CRITICAL ANALYSIS OF PALM KERNEL SHELL DEFORMATION, CRACK DEVELOPMENT AND FRACTURE /FAILURE IN A HOLLOW ROTOR CRACKER.

[1]ASHA SATURDAY, [2]KENNETH .O.ENEBE [3] OZOIHU EPHRAIM MADUABUCHI [4]EZEONWUMELU OGECHUKWU,

[1]ashiga4oxide@yahoo.com, [2]kenethenebe@yahoo.com,[3]ephraimozoihu@yahoo.com [4]oscargulfecho@ yahoo.com,

Scientific Equipment Development Institute SEDI,P. O .BOX 3205,Enugu ,Enugu State,Nigeria.

ABSTRACT

Cracking of palm kernel nuts is an integral part of the palm kernel oil processing. The effectiveness of cracking as regards kernel recovering with a little or no lost of kernel through breaking becomes paramount as it initiates further processing through which kernel oil is gotten. This work deepens into analysis deformation of kernel shell, crack growth, and fracture / failure of the shell as it result to spontaneous collision with the stony wall of the shelling drum and shattering of the shell and the kernel under this impact load. It also x-rayed parametric factors that. the kernel shell though hard but a brittle material with maximum deformation δ_{max} (m),and stiffness k,(N/m),mass of kernel nut m, (kg),angular speed ω (rad/sec) of the rotor, the diameters of the rotor and the shelling drum and hardness of the shelling drum wall affect cracking in the shelling environment while other physical properties of palm kernel nut –its sphericity,degree of digestion from the digester ,moisture content and instantaneous position during impact , and shell thickness are not under mind.

Key Words: *kernel shell deformation, impact force, crack growth, and fracture, rotor speed and diameter, and diameter of shelling drum.*

1.INTRODUCTION

Cracking of palm kernel is one of the most tedious work in the palm kernel oil processing. Apart from the drudgery in manual cracking is still characterized as the most effective cracking with high recoverying rate and cleanest kernel because of the human intelligence involved. No machine has been developed over the years to have selective cracking in terms of size of kernel nuts and impacting appropriately the

equivalent impact force on it. Hence, especially in local areas where there is a mixture of kernel in term of level of digestion, seasoning,sizes and varieties.

2.DIFFERENTIAL CRACKING

 A mixture of variaties of palm kernel nuts in terms of size and moisture contents necessitates differential cracking. If this is possible in applying flexible designs that could adapt human intelligence in cracking. Having a mixture ok palm kernel nuts can lead to the followings when cracked .Broken kernel resulting to poor recovering of kernel as they are subjected to the same impact force or cracking condition besides over drying. Unbroken kernel as a result of same cracking condition, difference in shell thickness,diffence in sizes, moisture content and the position of the spongy (fibrous end) side of the kernel at the instant of impact during cracking.

3.CONDITIONS THAT AFFECTS CRACKING

The importance of cracking for good kernel recovering provokes the engineering ingenuity to study critically deformation of the kernel shell, crack growth and fracture at the spontaneous instant of cracking. The factors that affects cracking as studied in

Scientific Equipment Development Institute In Enugu are as follows

    i.   Speed of the rotor.

    ii.   Size of the rotor.

    iii.   Size of the shelling drum.

    iv.   Mass of the kernel.

    v.   Moisture content of the kernel.

    vi.   Level of digestion in the digester.

    vii.   Shell thickness

    viii.   Instantaneous position of the spongy end of the digested kernel at the instant of impact.

    ix.   Sliding off tendency

4.SCOPE OF STUDY

This work is limited to studying surface deformation of palm kernel shell ,crack growth and fracture that necessitates cracking . Factors affecting cracking are mathematically x-rayed. Analyses done are on the basis of solid particle deformation using finite element analysis.

5.STATEMENT OF PROBLEM

Research shows that effective cracking that will help proper separation of palm kernel shells and nuts has not been met. This does

not mean no effective palm kernel shells and nuts separator(s) that will give optimum nuts recovery as no nut(s) will be lost with the shells or no shell will be found stick to the nut but the problem arise as a result of no means of effective cracking of a mixture of palm kernel in sizes and varieties peculiar to rural areas. Therefore ,this work explore analytically the factors that affect cracking, crack growth and fracture in the palm kernel shell that can be adapted in further design works.

6.SIGNIFICANT OF STUDY

This work is conceptualized for the visualization of the prevailing parametric factors that affect and initiates cracking of palm kernel nut(s) in a hollow rotor cracker throw deformation of the shell, crack growth and fracture using mathematical analytical method.

7. AIM AND OBJECTIVE OF STUDY

Various designs and research works have been done to achieve optimum cracking of palm kernel nuts where cracked mixture will be characterized with full nuts recovering, maximum shell separation with minimum or no broken nuts. It is therefore imperative to analytically study cracking as it affects palm

kernel nuts oil processing and provokes these aims and objectives

1. To conceptualize and analyze crack growth,and fracture for the brittle palm kernel shell.
2. To mathematically show design factors that can affect cracking.
3. To consider palm kernel nut shell under impact as particle under elastic deformation.
4. To used this analytical work as a synergy in further designs that will give optimum or most effective cracking.

8.ANALYSIS

Cracking as a phenomenon will be analyzed first to show the mechanism of the process via the determination of the parametric factors , and the forces that necessitate cracking in the centrifugal hollow cracker. Elastic deformation analysis, crack growth, and fracture of the brittle hard kernel shell

8.1. MECHANISM OF CRACKING.

The centrifugal hollow rotor is in rotational motion with the exits describing a perfect circular path that depicts its size, concentric

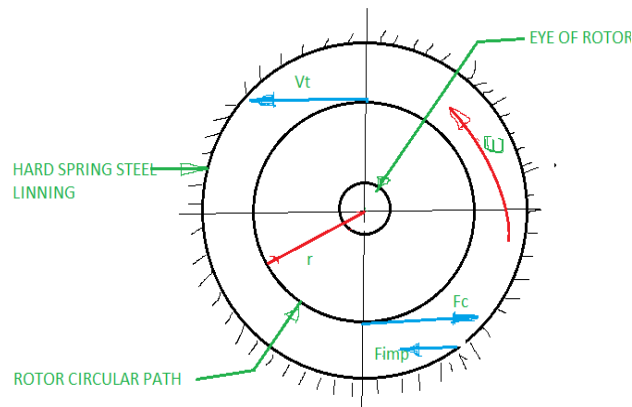to the internal diameter of the shelling drum. Consider fig.1.

Fig.1.Schematic Representation Of Shelling Drum And Rotor Assembly

The kernel of mass M ,(Kg)is said to be in a circular motion with rotor and exits at an angular speed ω (rads/sec), at a radius ,r,(m) for the axis of rotation of the eye of the rotor.

$$D = 2\mathbf{r} \qquad (1)$$

$$\omega = \frac{\pi DN}{60} \qquad (2)$$

$$V = \omega r \qquad (3)$$

$$a = \frac{V^2}{r} = \omega^2 r \quad (4)$$

The kernel is subjected to centripetal force F_C (N), of the hollow rotor required to collide the kernel nuts against the wall of the shelling drum lined with spring steel material .

$$F_C = Ma = M\omega^2 r \quad (5)$$

At exit, the kernel leaves tangentially at an instantaneous linear velocity and distance ,x,(m) at instant time, (Δt) to the wall of the drum

$$V = \frac{x}{\Delta t} = \omega r \quad (6)$$

However, mass is constant but weight varies with speed ,at the instantaneous speed,the weight is assumed constant. The momentum of the kernel is

$$mometum = MV \qquad (7)$$

Mass M of the kernel and the speed of the affects the amount of impact or collision with the wall of the shelling drum. From Newton's second law of motion and the third law of motion,

The impact force F_{IMP}(N) is determined as

$$F \propto \frac{\Delta MV}{\Delta t} = F_{IMP} \quad (8)$$

$$F_{IMP} = Ma = M\frac{V}{r} = M\omega^2 r \quad (9)$$

$$F_{IMP} = F_C \qquad (10)$$

Considering the law of conservation of linear momentum, assume the wall of the

shelling drum to be a rigid body,the kinetic energy of the kernel K_E

$$K_E = \frac{1}{2} MV^2 = \frac{1}{2} M\omega^2 r^2 \qquad (11)$$

Deformation of the kernel shell is conceptualise by considering the elastic deformation. The force required for the deformation is analytically equal to the impact force as well as the centripetal force.hence,hooke's law

$F = Ke$ (12) for elastic body

Where,

e=extension

K=Elastic constant or stiffness of the body

This could be written as equation (13)

$$F_{IMP} = S\delta = K\delta \qquad (13)$$

Where

e=δ =extension   as   elastic deformation(deflection)(m)

K=S=Stiffness of the kernel shell(N/m)

Fig 2 show the impact or collision of kernel nuts and the hard spring steel surface both possessing different stiffness –Kn,s and Kn,p for spring steel and kernel respectively.
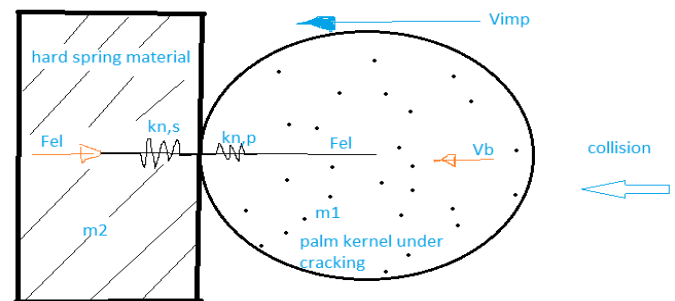

Fig.2 representation of collision between
the kernel and the spring steel surface.

The impact velocity (Vimp) ,masses m1 and m2 of colliding bodies are necessary for collision and to satisfy the Newton's laws of motion.
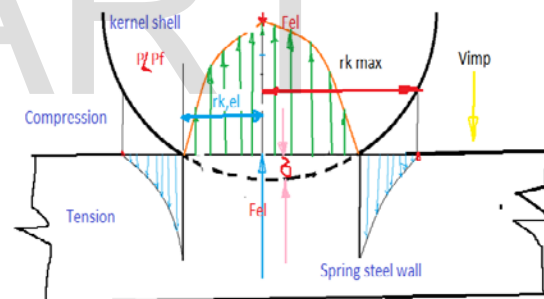

Fig 3.Characteristic pressure distribution
$p(rk$) in kernel shell wall in contact with
spring steel lining during elastic deformation
during impact from the rotating rotor.

Hertz theory of elastic deformation characterisedn elastic deformation at contact during impact. The axial loadingin the

contact area as in fig.2. is favoured by the impact velocity(Vimp),that geared crack propagation owing to the difference between the colliding bodies stiffness (Kn) and masses. For deformation to occure the contact radius ,internal pressure,force are functions of kerel average radius *R,stiffness and deformation behavior of theb two bodies in contact(the kernel shell and the spring steel material) . In fig .3 the elliptical pressure(Pel) distribution in the circular contact area of a radius($r_{K,el}$)

$$\left(\frac{P_{el}}{P_{max}}\right)^2 = 1 - \left(\frac{r_k}{r_{k,el}}\right)^2 \qquad (14)$$

$$r_k \le r_{k,el}$$

But for a totally deformed area ,the radius is greater than the contact radius;

$$r_{k\ max} \ge r_{k,el} \quad (15)$$

Hertz contact maximum pressure is given

$$P_{max} = \frac{3F_{el}}{2\pi r_{k,el}^2} \qquad (16)$$

$$r_{k,el} = \left(\frac{3R^*F_{el}}{2E^*}\right)^{1/3} \qquad (17)$$

E^* =Effective modulus of elasticity of contact partner.

$E_2 >> E_1 , E_2 \to \infty$,thus,

$$E^* = 2\left[\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right]^{-1} \qquad \approx \left(\frac{2}{1-\nu_1^2}\right)E_1$$

(18)

ν =poisson ratio

The effective contact kernel radius R^*

$$R^* = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} \approx R_1 \qquad (19)$$

$For\ R_2\ >> R_1$

The relationship between   elastic contact force and the displacement, δ, in normal direction is non-linear form by Hertz (Hertz, H, (1882)

$$F_{el} = \frac{2}{3}\ E^*\sqrt{R^*\delta^3} \quad (20)$$

$$F_{el} = \frac{4}{3}\frac{E_1}{1-\nu_1^2}\sqrt{\frac{d_1}{2}}\ \delta^3 \quad (21)$$

where

d_1=diameter of kernel

δ=displacement

$$\delta = r_{k,el}^2/R^* \quad (22)$$

From the law of conservation of energy (Antonyuk, S., Khanal, M., Tomas, J., Heinrich, S., Mörl, L.: 2006)

$$\frac{m^*}{2}\left(\frac{d\delta}{dt}\right)^2 = \frac{m^*v^*}{2} - \frac{4}{15}E^*\sqrt{R^*\delta^5} \quad (23)$$

m^*=effective mass of kernel.

v^*=effective impact velocity

$$m^* = \left(\frac{1}{m_1} + \frac{1}{m_2}\right)^{-1} \approx m_1 \qquad (24)$$

$$m_2 >> m_1 \quad , m_2 \to \infty$$

$$m^* = \left(\frac{1}{v_1} + \frac{1}{v_2}\right)^{-1} \approx v_1 \qquad (25)$$

$$v_2 >> v_1 \quad , v_2 \to \infty$$

v_1 = velocity of the kernel and it is the impact velocity Vimp,

And m_1 is the mass of kernel

Energy ,E, to deform an elastic body

$$E = \frac{1}{2} F\delta = \frac{1}{2} K\delta^2 \qquad (26)$$

Equating this to Kinetic energy from the law of conservation of energy

$$\frac{1}{2} K\delta^2 = \frac{1}{2} M\omega^2 r^2 \qquad (27)$$

Hence the speed required to deform the kernel shell elastically at a maximum deformation i.e crack formation and fracture or failure(shattering of the shell)

$$\frac{1}{2} K\delta_{max}^2 = \frac{1}{2} M\omega^2 r^2 \quad (28)$$

The angular speed $\omega, rad/sec$ required for palm kernel nut to deform maximumly,

$$M\omega^2 r^2 = K\delta_{max}^2 \qquad (29)$$

$$\omega^2 = \frac{K\delta_{max}^2}{Mr^2} \qquad (30)$$

$$\omega = \frac{\delta_{max}^2}{r} \sqrt{\frac{K}{M}} \qquad (31)$$

Therefore, the maximum angular speed $\omega(rad/sec)$ that can cause maximum deformation

$$\omega_{max} = \frac{\delta_{max}^2}{r} \sqrt{\frac{K}{M}} \qquad (32)$$

This is vital in the design of an impeller hollow rotor palm kernel nuts cracker, it follows that the smallest size of palm kernel nut will require highest speed to deform it maximally.thus maximum deformation force

$$F_{IMP} = M\omega^2 r = M\omega_{max}^2 r \quad (33)$$

$$F_{max} = M \left(\frac{\delta_{max}^2}{r} \sqrt{\frac{K}{M}}\right)^2 r \qquad (34)$$

$$F_{max} = \frac{K\delta_{max}^4}{r} \qquad (35)$$

Considering a kernel shell to be isotropic elastic material,in a 3-D,hookew's law

$$\varepsilon_x = \frac{1}{\varepsilon}\left(\sigma_x - v(\sigma_y + \sigma_z)\right) \quad (36a)$$

$$\varepsilon_y = \frac{1}{\varepsilon}\left(\sigma_y - v(\sigma_x + \sigma_z)\right) \quad (36b)$$

$$\varepsilon_z = \frac{1}{\varepsilon}\left(\sigma_z - v(\sigma_x + \sigma_y)\right) \quad (36c)$$

The strain energy U, required to deform the kernel shell elastically

$$U_O = \frac{1}{2E}\left(\sigma_x{}^2 + \sigma_y{}^2 + \sigma_z{}^2 - 2\mathbf{v}(\boldsymbol{\sigma_x\sigma_y} + \boldsymbol{\sigma_y\sigma_z} + \boldsymbol{\sigma_z\sigma_x})\right) + \frac{1}{2G}\left(\tau_x{}^2 + \tau_y{}^2 + \tau_z{}^2\right)$$
$$(37)$$

The stresses and strains build up as a result of impact of the kernel nut on the wall of the shelling drum lead to crack formation, Crack propagation occurs when the released elastic strain energy is at least equal to the energy required to generate new crack surface and sudden failure of the shell as a brittle material when dried ,this failure is fracture as the shell is critically stressed. Hence,

$$\sigma_{max} = \sigma_{critical} \quad (38)$$

For maximum principal stress criterion

$$\sigma_{max} = K_t\sigma_{normal} \quad (39)$$

The stress concentration factor or stress intensity factor. K_t

$$K_t = \sigma\sqrt{\pi a f\left(\frac{a}{c}\right)} \quad (40)$$

$$f\left(\frac{a}{c}\right) = 1$$

If $a << c$

Then ,the critical condition for fracture is given

$$K_t = K_{tc} \quad (41)$$

And ac is the maximum length of crack

The energy stored in the deforming kernel shell per unit volume of the kernel is the strain energy density

$$U = \int U_O \, dv \quad (42)$$

$$U_O =$$

$$\int_0^\varepsilon \delta d\varepsilon = \frac{1}{2}\delta_x\varepsilon_x = \frac{1}{2}\frac{\delta_x{}^2}{E} = \frac{1}{2}\varepsilon_x{}^2 E$$
$$(43)$$

$$U_{vol} = \frac{1-2\mathbf{v}}{6E}[(\sigma_1 + \sigma_2 + \sigma_3)^2]$$
$$(44)$$

The analytical method idealized the parametric consideration for the design and development of hollow impeller palm kernel cracking machine.

9.CONCLUSION

Many factors –moisture content palm kernel, speed of rotor, thickness of the shell, the magnitude of impact force,size and weight of kernel etc are responsible for effective craking.   Analytically, this work has exposed these factors that can be adapted for further designs to get adequate and optimal design. Hence, deformation analysis of the palm kernel shell from crack propagation, growth and fracture enables the visualization of the processes and factors that will govern effective cracking. Thus, this mathematical analysis will help in using parameters to design an efficient palm kernel cracking machine.

REFFERENCES

1. Adebayo AA (2004). Development and Performance Evaluation of a Motorised Palm Nut Cracker. Proceedings of the Nigerian Institution of Agricultural Engineers (NIAE), 26: 326-330.

2. ASAE Standards ASAE368-1 (1980). Compression Test of Food Materials of Convex Shape. Agricultural Engineering year book. American Society of Agricultural Engineers, St. Joseph,

3. Michigan. Cox DR (1952). Physical Planning of Experiments. John Willey, New York. Dev DK,

4. Satwadhar PN, Ingle UM (1982). Effects of Variety and Moisture Content on Selected Physical Properties of Sorghum Grain. J. Agric. Engr., 19(2): 43-48.

5. Ezeaku CA, Akubuo CO, Onwualu AP (1998). Measurement of the Resistance of Bambara Groundnut Seed to Compressive Loading. J. Agric. Engr. Technol., 6: 12-18.

6. FAO (1983). Agricultural Services Bulletin, No. 22. Makanjuola GA (1972). A Study of Some of the Physical Properties of Melon Seeds. J. Agric. Eng., 17: 128-137.

7. Mohsenin NN (1978). Physical Properties of Plants and Animals Materials. Gordon and Breach Science Publishers. 2nd Edition, New York.

8. Montgomery DC (1976). Design and Analysis of Experiments. John Willey, New York.

9. Olaniyan AM (2006). Development of Dry Extraction Process for Recovering Shea Butter from Shea Kernel. Unpublished Ph.D thesis, Department of Agricultural Engineering, University of Ilorin, Nigeria.

10. Paulsen MR (1978). Fracture Resistance of Soybean to Compressive Loading. Trans. Am. Soc. Agric. Eng., 21(6): 1210-12.

11. Hertz, H, (1882).: Über die Berührung fester elastischer Körper. J. Die Reine Und Angewandte Mathematik **92**, 156–171 (1882)

12. Antonyuk, S., Khanal, M., Tomas, J., Heinrich, S., Mörl, L.: 2006 Impact breakage of spherical granules: experimental study and DEM simulation. Chem. Eng. Process. **45**, 838–856 (2006)

IJOART